Applications of RS, GIS and GPS technologies in research, inventory and management of wetlands in China

CUI Li-juan [1], Anna van Paddenburg[2], ZHANG Man-yin[3]

[1] *Wetland research Centre, Chinese Academy of Forestry, Beijing 100091, P. R. China*

[2] *Wetlands International-China, Beijing, 100011, P. R. China*

[3] *Northeast Normal University, Department of Environmental Science and Engineering, Changchun, 130024, P.R. China*

Abstract: This paper introduces the state of waterlands in China and discribes the applications of Remote Sensing (RS), Geographical Information System (GIS) and Global Positioning System (GPS) in wetland research, including land-coverclassification and change detection, wetland evolutionary processes, landscape-change analyses, channel migration, flood and wetlands resource monitoring and spatial quantitative analyses/modeling, ecosystem service evaluation, ecological processes and risk assessments, disease control, water quality monitoring/modeling, pollution monitoring/modeling, wetlands hydrology, wetland information systems and WebGIS. The limitations and needs for optimal use of these technologies are discussed, such as the limited advanced technical knowledge and skills, low awareness and capacity, unclear link between GIS output and policy making, lack of supporting policies and standards, lack of a wetlands geo-information networklimite, and the use of these techniques in wetland research. It is suggested that for realising true applications of RS , GIS and GPS technologies, the availability, accessibility, reliability, homogeneity, and continuity of wetlands-related geo-information, enabling environment, policies and standards, and funding are needed.

Keyword: Geographic Information System (GIS); Remote Sensing (RS); Global Position System (GPS); 3S; Wetland

CLC number: P941.78 **Document code:** B **Article ID:** 1007-662X(2005)04-0317-06

Introduction

Geographic Information Systems (GIS), Remote Sensing (RS) and Global Positioning Systems (GPS), which are often abbreviated to Three-S technologies in China, play significant roles in many extensive integrated research related to space and time, and are valuable techniques and tools in obtaining, storing, managing, analyzing and visualizing ecological, water resource and socio-economic data for effective and efficient inventory and optimal policy and decision making. In China these advanced technologies started to gain attention soon after the open door policy in 1978, the Chinese Academy of Sciences (CAS) is the first institute to apply the technologies (He and Jiang 1995; Zhu *et al.* 2002).

Three-S technologies often were applied in land use planning, land resource surveying, crop yield evaluating, disaster assessing, flood monitoring, fire preventing, and desertification controlling by interrelated research institutes, universities and government sectors. However, little research has been devoted to the use of Three-S technologies in the field of wetlands. The first part of this paper briefly describes the history of wetlands research, inventory and management in China; the second one describes the development and advancements of the use of the Three-S technologies in the field of wetlands; finally, in conclusion, limitations and needs for optimal use of the Three-S technologies for the sustainability of wetlands in China are highlighted.

Foundation item: This project was supported by National Natural Science Foundation of China (No. 30270275)

Biography: CUI Li-juan (1968-), female, Ph.D., associate professor, Wetland Research Centre, Chinese Academy of Forestry, Beijing 100091, P. R. China E-mail: clj-lkybsh@sohu.com

Received date: 2005-04-04

Acceptable date: 2005-06-20

Responsible editor: Song Funan

State of wetlands in China

China is a country with scarce water resources. Statistics show that China has lost the lakes of 32.5 billion m^3 (NWAP 2002). Approximately half of China's coastal wetlands have lost due to reclamation. About 3-million hm^2 of marshland in Sanjiang Plains, the largest marsh area in China, have been converted to farmland (NWAP 2002). Of the 1 200 rivers monitored, 850 are polluted and about 50% of lakes have become eutrophic (NWAP 2002). The water bodies of more than 90% of cities are polluted and 50% of major cities have no drinking water that meets acceptable hygiene standards (NWAP 2002).

In 1992 the Chinese government signed the Râmsar Convention and designated seven wetland sites as Wetlands of International Importance. The flood disaster in 1998 raised awareness of the government and public for the importance of wetlands conservation, and the government designated again fourteen sites as wetland conservation in 2002. The first wetlands resource investigation has recently been completed (1995-2001) and the results will be published shortly. The latest figures published by State Forest Administration of China reveal that in China, wetlands larger than 100 hm^2 amount to 38.48 million hm^2, which include marsh wetlands of 13.7 million hm^2, coastal wetlands of 5.94 million hm^2, river wetlands of 8.21 million hm^2, lake wetlands of 8.35 million hm^2, and reservoirs and ponds of 2.28 million hm^2. Now the total of wetland with international importance amounts to 21, and according to the first wetlands investigation there are 376 wetlands with national importance. The conservation and wise use of the wetlands of China have been listed as a priority area under China's Agenda 21. The strategy outlined under the National Wetlands Conservation Program (2002–2030) aims to establish 713 wetlands nature reserves, designate another 80 Ramsar sites, effectively protect more than 90% natural wetlands and restore 1.4 million hm^2 of wetlands (NWCP 2002). The development and implementation of the National Wetlands Con-

servation Action Plan (2002-2010) and the 2002-2030 National Wetlands Conservation Program are preliminary outputs of the strategy.

In China, wetlands research and inventory started in the early of the 1950s. The research topics mainly included inventory, classification, formation and evolution, ecological protection, pollution control, wise use and management of wetlands. On the basis of the research on marsh, lake, mangrove, and coral reef ecosystems, we have obtained a preliminary database of China's wetland resources. The Northeast China Institute of Geographic and Agricultural Biology, the leading CAS institute involved in wetlands research, was established in 1958. Later the Lake Institute in Nanjing was established and is now the leading research institute in comprehensive limnology and watershed research. Geographical research is concentrated on the Yangtze River Basin, western region, and southeast coastal zone.

Wetlands and the Three-S technologies

The Three-S technologies were very seldom employed in the research related to wetland in the 1980s, and they gained a wider appreciation in the late of 1990s. Until now the technologies are mostly utilized by research institutes and universities, and their uses are still very sporadic in wetlands inventory and so far hardly in the management and support decision-making processes. The Three-S technologies were used by the Wetland Resources Monitoring Centre in the first national wetlands resource investigation (a department within the State Forest Administration). Some provinces (e.g. Guangdong, Hebei, Jiangxu, Hainan) with stronger financial support and technical expertise have attempted to use remote sensing and GIS in their investigation.

The Three-S technologies have great potentials in many kind of research related to wetland. Land classification and change-detection techniques have been applying for mapping, investigation of wetland evolutionary processes, landscape-change analyses, channel migration, flood, and wetlands resource monitoring. Spatial quantitative analyses and modeling are valuable methods in ecosystem service evaluation, wetland ecological processes and risk assessments, wetland disease control, water quality monitoring and modeling, wetlands pollution monitoring and modeling, and wetlands hydrology.

Land-cover classification and change detection

Remote sensing can handle large amounts of input data and provides an effective and efficient means to describe the characteristics of a wetland system (Koneff & Royle 2004) and its integral importance within watersheds and river basins. Land cover mapping and change detection (Alonso-Pérez *et al.*, 2003) are the most important and typical applications of remote sensing data. Information about change is necessary for updating land cover maps and the management of wetlands resources which usually reflect the impact of natural and human activity.

The formation and evolutionary process of wetlands in China have been studied since the late of 1950s. Now many universities and institutes have improved their landscape-change analyses by using remotely sensed imagery to evaluate loss and recovery of wetlands over the last few decades. The Northeast China Institute of Geographic and Agricultural Biology investigated mire fragmentation on the Sanjiang plains over the past decades and observed a rapid reduction of 51.33% of the area of mire from 1980 to 1996 (Wang *et al.* 2002). An evolution investigation on the Qinghai Lake over the past 25 years revealed fragmentation and shrinkage of the lake and a drop in surface water level around 2 m from 1975 to 2000 (Shen and Kuang 2003b). Zhao *et al.* (2003) used remote sensing to study the impact of lake restoration on land-use and riparian landscape. The Lake Institute in Nanjing used Landsat imagery to support the monitoring of the entry of sand and silt into Poyang Lake (Zhao and Fu 2003) and Dongting Lake (Du *et al.* 2001). Lake shore collapsing and silting of Chao Lake were also investigated by means of change detection in land cover (Yang *et al.* 1999).

Yue *et al.* (2003) investigated landscape-change data of the newly created wetland in the Yellow River Delta in 1984, 1991, and 1996 by integrating Landsat TM images of the newly created wetland in the four seasons of the each year. Channel migration on the delta was monitored by a series of time-series Landsat images spanning a period of approximately 19 years and related to natural and human processes (Yang *et al.* 1999). Another shoreline migration study of the coastline along Bohai Bay of the past 130 years was done using these advanced technologies in combination with historical documents (Jiang *et al.* 2003).

Areas inundated by floods and floodplains could be mapped effectively with remotely sensed data. The technology has been extensively used in the estimation of inundated area and the extent of flood damage along the Yellow River, Yangtze River, Huaihe River and many more river basins (Zhang *et al.* 2002).

Considering wetlands resource monitoring, Li *et al.* (2003) monitored the distribution area of mangrove. Hyper-spectral images might hold potential for identification of mangrove communities (Li *et al.* 2003). Biomass estimation of wetlands vegetation was made using hyper-spectral imaging spectrometry in Poyang Lake (Tong *et al.* 1997). Gu *et al.* (2003) presented algorithms to be used for the detection of red tides using remote sensing, based on bio-optical principles including using the variation velocity of chlorophyll-a concentrations and temperature change of sea surface as well as multi-spectral water leaving radiation.

Spatial quantitative analyses and modeling

Three-S technologies have spatial analysis capabilities to quantitatively assess ecosystem services (Zhao *et al.* 2004), perform risk assessments and model ecological processes of wetlands (Smith *et al.* 2003). They also are valuable tools to support water quality, pollution and hydrology models for wetlands management.

On Chongming Island, the largest alluvial island in the world, the total value loss in land-use and ecosystem services on Dongtan between 1990 and 2000 reached 62%. This massive decrease is largely attributed to the 71% loss of wetland tidal flats (Zhao *et al.* 2004). An ecological risk assessment has been implemented on the Yellow River Delta (Xu *et al.* 2004). In this study indices and formulas were established for measuring degrees of ecological risk and damage to ecosystems. Using a combination of remotely sensed data, historical records and survey data, and with the assistance of GIS techniques, the area was classified into several risk zones. In the context of ecological processes, Higgit (2001) modelled the source and conveyance of sediments from the catchment area to the Three Gorges Reservoir to support management strategies. Here, the ecological process between land cover, climatic and topographic variables with sediment yield were modelled.

The area of wetlands water surface is continuous in a dynamic state and, therefore, difficult to be calculated accurately. It is possible to calculate water quality parameters (e.g. chlorophyll-a,

total phosphorous (TP), and secchi disk transparency (SDT)) using RS to determine extent of eutrophication. Concentrations of suspended substances and chlorophyll-a in Taihu Lake and Dianchi were obtained by remote sensing to monitor the level of eutrophication (Shen and Kuang 2003a). A fuzzy logic (FL) model was developed to predict algal biomass concentration in the eutrophic Taihu Lake, which combined data-mining techniques with heuristic knowledge. Remotely sensed imageries have also been used extensively to support the modeling of non-point source pollution entering wetlands by means of surface and ground water (Wang *et al.* 2002; Zhou *et al.* 2003). A quantitative model was designed to simulate the nutrient reduction function of the wetland in the Liaohe Delta, highlighting the great potential to use the estuary wetland as a final filter for nutrient enriched river water, and reduce the possibility of coastal water eutrophication (Li *et al.* 2003).

These technologies were also commonly used to support hydrological modeling and flood monitoring (Zhu *et al.* 2003; Wan *et al.* 2000; Hu *et al.* 2003; Zhou *et al.* 2003; Ma *et al.* 2001). Zhu *et al.* (2003) reviewed the integration of watershed hydrological models with remote sensing and GIS. Wan *et al.* (2000) commented that, by using GIS, distributed hydrological modelling could be improved, for GIS-based distributed hydrological model supports a variety of hydrological variable (or parameter) and spatial information which can be cost-effectively obtained using remote sensing technique. The Three-S technologies provide an improved means to support hydrological models to measure the different hydrological variables or processes related to the water and energy cycle. In a hydrological model, runoff can be used to determine watershed geometry, drainage network, and other map-type information for distributed hydrologic models and for empirical flood peak, annual runoff or low-flow equations. It also provides inputting data such as soil moisture or delineated land use classes that are used to define runoff coefficients. Peak flow and estimation of runoff coefficients can provide useful initial conditions for flood forecasting and for monitoring of flooded areas.

The combination of remote sensing and GIS-based hydrological quantitative modeling has been widely implemented on many wetlands in China. Many researchers have used hydrological models from abroad, e.g. SWAT (Hu *et al.* 2003), BASINS and PLOAD (Zhou *et al.* 2003).

Other key hydrological parameters are precipitation and evapotranspiration (ET). Improved analysis of rainfall can be achieved by combining satellite and conventional gauge data (Wang *et al.* 2003; Jiang *et al.* 2003). Remotely sensed data can be used to measure variables in the energy and moisture balance models which will give information on ET (Jiang *et al.* 2003; Pan and Liu 2003). At the Yellow River Delta, Pan and Liu (2003) used SEBAL (Surface Energy Balance Algorithms for Land) to compute ET based on RS images (NIR and IR bands). Net radiance flux, soil heat flux, and sensible heat flux were computed and ET energy was eventually calculated with the latent heat flux.

Wetlands information system

GIS provides a way to effectively and efficiently store vast amounts of information related to wetlands which are useful for management at various levels. These kinds of systems have been realized widely in China. A national integrated system using Three-S technologies has been developed for monitoring and evaluating flood disasters (Zhang *et al.* 2002), which plays an important role in flood mitigation during the trial and has become a key part of the flood management system. In Wuxi, located in the Taihu Lake Catchment, an environmental information system (known as EGIS) has been developed for monitoring purposes (Zhu *et al.* 2003). He *et al.* (2001) established a spatial database of the Houzhaihe Catchment at Puding (Guizhou) for hydrological modeling using parameters obtained from RS for better management of a variety of information. GIS can also be useful for decision-making system aimed for the control of water pollution (Zhang *et al.* 2002). The management of East-Liao river valley in Jilin Province also applies EGIS (Li *et al.* 1999).

WebGIS

WebGIS is a very useful tool to improve wetlands management and promote sustainable development by facilitating solutions to common problems and ensuring the communication of results on a compatible GIS platform, to assist in the promotion of information exchange; and to act as a clearinghouse for the existing knowledge in wetlands management. Recently, the applications of WebGIS on wetland field are getting more and more attentions. Wu *et al.* (2003) recognized the requirements to set up a Forest Resource Management Information System based on WebGIS. The Academy of Forestry Inventory and Planning (SFA) has an upcoming project (2004–2009) to set up a Geo-information platform for management of desertification, forest resources, flora, fauna, forest diseases (pest/locust), fire, nature reserves, wetlands, the monitoring of the 6 National Programmers of SFA, and the network of 14 forest environmental monitoring research stations. However, no practical WebGIS within the field of wetlands have been implemented so far.

Limitations and needs for optimal use of the Three-S technologies

Technical limitations

The extraction of geo-information from remotely sensed images is a complicated process. It requires the use of quantitative models to interpret the radiation data collected in space. The validity of the processing and interpreting methods often determines the true applicability of the output GIS product. Few authors outline metadata which details data acquisition, processing and geo-information extraction. In almost all of the above studies on change detections were between a large time span. Much of the detection of change was done by overlaying classified data (e.g. Zhao *et al.* 2003). No studies have been attempted on more subtle change detection, possibly due to the requirement of more accurate acquisition of geo-information. It is also observed that most are limited to the use of optical remotely sensed data, and few have attempted to use the hyper-spectral imagery in their work. Sheet flow, information on groundwater systems of wetlands are difficult to be modeled as many factors need to be considered. The vertical hydraulic linkage in peatlands is still unclear. Also, equations used in hydrological models are often restricted to basins and climatic/hydrological regions.

Huang and Xia (2001) recognized similar issues have been barriers in sustainable water quality management in China, namely, data reliability, concerns in system complexity and methodology validity, and limitations of techniques. The use of the Three-S technologies within wetlands applications may elicit a breakthrough in wetlands inventory and management, however spatial information obtained by these techniques must be scruti-

nized. Without knowledge and understanding of advanced technical issues such as limitations of change-detection techniques, geometric corrections, the extrapolation of noise through data integration, exogenous effects of climate, precipitation, etc. the use of such data will lead us to a virtual world and does not bring us closer to the true representation of reality, which impedes the sustainable development of wetlands.

Key actions: Advanced research in improving quality and quantity of wetlands data; Capacity building in advanced analytical and modeling applications of remote sensing and GIS for wetlands research, inventory, and management.

Human resources and capacity building

Awareness on the use of the Three-S technologies at national level has increased recently. However, those directly involved in wetlands inventory and management at local and provincial level still have a limited understanding for even the basic ecological goods and services of wetlands providing, let alone the use of the Three-S technologies for wetlands inventory and monitoring. Two pilot projects on monitoring wetlands nature reserves are currently ongoing in internationally important sites, Sanjiang and Dongzhai, to identify and monitor biodiversity, surface water level wetlands hydrology, and wetland-climate relation. However, it has been noted that the lack of skilled staff, equipments, low capacity and no understanding on the implications of GIS expert's activities in the field are barriers to the successful implementation of these projects and continuity of the use of these technologies. This low capacity results in poor quality of standard requirements being met. Moreover, the lack of skilled staff hampers the systematic identification and collection of ground truth data for a variety of variables. Without a systematic approach, inconsistent procedures and setting of standards, long-term commitment from local and provincial staff cannot be maintained. Huang and Xia (2001) outlined usefulness of research outputs for policy and decision making, difficulties in policy implementation, and necessity for training programs in their review on barriers to sustainable water resource management in China.

The manual for an inventory of Asian wetlands provided a structured framework for wetlands inventory and management, including the use of remote sensing and GIS applications for mapping, storing, analyzing and retrieving of wetlands bio-physical and management features. Capacity building and training in this systematic approach may prove to be very useful to support a standardized nationwide wetlands inventory. Wetlands International has proposed to establish an assistance program for implementation of the manual at national, provincial and local levels. Qualified and capable human resources are fundamental to make Three-S a viable technological option within sustainable wetlands management. To bridge this human resource gap we must focus on generating awareness about the extensive applicability of the technology and build the capacity of wetland professionals, scientist, policy and decision makers and government sectors at national, provincial and local levels.

Key actions: Awareness raising at implementation level (local and provincial) and strengthening the existing awareness at national levels; Awareness raising in linking GIS output to policy and decision making; Capacity building on wetlands inventory and monitoring using the Three-S technologies at all levels of government, including the collection of ground truth data; Capacity building in providing high quality, useful and understandable GIS output for policy and decision making; Intensive short-term training courses and longer-term distance learning courses.

Enabling environment

To make sure capacity building and advanced technical support is sustainable and effective at national, provincial and local levels, an enabling environment must be ensured. A fundamental component in an enabling environment is an infrastructural and legal framework. This would consist of a set of policies and standards, facilitating network and clearing house, and good quality and quantity geo-information related to wetlands.

Policies and standards

A substantial amount of geo-information is now available as a result of numerous studies and research projects. However, such information is dispersed and inaccessible. A great obstacle in China is the poor information sharing between different research institutes and government organizations at all levels, which undoubtedly results in inefficiency and duplication of data. Awareness in that merging data is more valuable than the sum of separate datasets will be essential. This could be realised by a set of policies and/or financial incentives for sharing geo-information.

Another major obstacle in the use of the Three-S technologies is that geo-information is heterogeneous, different reference systems are used, and inadequate information about the projection systems are adopted. A national/international spatial reference system and the parameters to convert the coordinate systems to this system are imperative. Data integration poses another problem due to the different spatial units adopted for data collection. Administrative boundaries are used as basic spatial units for socioeconomic database whereas the natural geo-hydrological processes follow the watershed boundaries. The development of consistent standards and procedures will enhance the use of these technologies within sustainable wetlands inventory and management. Considerable effort is required to integrate datasets to produce a consistent national dataset.

Key actions: Setting of policies, standards, procedures related to the use of the Three-S technologies and sharing of geo-information; Awareness raising on the improved value of geo-information when shared; Financial incentives to promote the sharing of geo-information; Wetlands geo-information network and clearing house.

Computer technology is not the problem in China, although it is sometimes difficult to keep up with the speed of the development of GIS software. The greater difficulty is the gap between remote sensing/GIS experts, wetlands experts and wetlands policy and decision makers. It is the absence of a wetlands geo-information network and clearinghouse. Therefore, a framework for data collection and data exchange to facilitate the flow of geo-information concerning wetlands is desirable. This will not only enhance the continuity and timely collection of relevant spatial data, but also strengthen the knowledge and understanding of what kind of data is required for each application and how and why ground truth should be identified and collected. Besides, it is essential to integrate the network of wetlands spatial databases into the network of spatial databases concerning water resources as a whole to address issues of common interest. This will stress the priority of the sustainable management of wetlands in groundwater, watershed, and river basin, also its role in poverty reduction and biodiversity conservation. Hence, effort has to be invested in developing a sound national wetlands geo-information infrastructure to support the common goals of

various government sectors for the management and monitoring of natural resources and environment. International and inter-departmental cooperation should be encouraged. We need to take advantage of the technology together and develop multilateral projects to combine the knowledge we have, bring it together and achieve China's sustainable development goal.

Key actions: Awareness raising in the importance of establishing a national wetlands geo-information infrastructure in order to promote sustainable wetlands management and development overall and understanding its link to decision making processes; Establishing national wetlands geo-information infrastructure consisting of a network and clearinghouse; Integration of wetlands spatial database to water resource database.

Funding

A cross-disciplinary issue is addressing in awareness raising and capacity building, but always lack of funding to support continuing project activities. Without sustainable sources of funding qualified and capable human resources will not be available to continually and optimally make use of the Three-S technologies. Fundraising strategies should be put in place. It would be desirable to have a specific funding mechanism for raising awareness and building capacity for the optimal use of this technology to support sustainable wetlands management and sustainable development as a whole.

Key actions: Dedicating funding to create awareness and build capacity; Development of fundraising strategy; Development of funding mechanism to specifically use for the development of Three-S technologies within wetlands inventory and management.

Conclusions

Three-S technologies are effective and efficient medium to integrate large amounts of data for decision support systems, especially for a vast country such as China aiming for sustainable development. Albeit dispersed, China has accumulated geo-information on water resources and ecological resources of wetlands, yet a comprehensive study on the socio-economic values of wetlands is still lacking. The combined use of geo-information on ecological, water resource and socio-economic values of wetlands will prove to be indispensable to comprehend that the sustainability of watersheds and river basins depending on the sustainability of wetlands. This calls for a systematic approach to wetlands inventory and management and the integration of wetlands management.

Over the past years, a lot has been achieved in the field of raising awareness and policy development relevant to the sustainable management of wetlands in China. The technology has also gained greater recognition within relevant government sectors at a national level. This brief account on the application of the Three-S technologies within wetlands research, inventory and management brings to light in technical limitations, lack of qualified and capable human resources, an enabling environment, and in particular, a lack of funds still hamper the optimal use of the Three-S technologies for wetlands research, inventory and management in China. To realize a more exhaustive and reliable use of the Three-S technologies and to bridge the gap between remote sensing/GIS experts and ecological experts, and between researchers and policy and decision makers, efforts should be concentrated on raising awareness and capacity building amongst government and research institutes, and the development of innovative fundraising strategies. The hardware technology is present amongst those involved in wetlands, but much needs to be done to increase awareness and develop capacity to eventually realize the availability, accessibility, reliability, homogeneity and continuity of geo-information relevant to the sustainability of wetlands. International and inter-departmental cooperation should be encouraged. We need to take advantage of the technology together and develop multilateral projects to combine the knowledge we have, bring it together and achieve China's sustainable development goal.

Acknowledgement

We thank State Forest Administration and the Chinese Academy of Sciences with its many research institutes for providing the information required for this paper. Also, a sincere thank to Bai Yajun for her patience and endless support in discussions and email correspondence.

References

Alonso-Pérez Fernando, Arturo Ruiz-Luna, John Turner, *et al.* 2003. Land cover changes and impact of shrimp aquaculture on the landscape in the Ceuta coastal lagoon system, Sinaloa, Mexico [J]. Ocean & Coastal Management, **46**(6): 583–600.

Du Yun, Cai Shuming, Zhang Xiaoyang, *et al.* 2001. Interpretation of the environmental change of Dongting Lake, middle reach of Yangtze River, China, by ^{210}Pb measurement and satellite image analysis [J]. Geomorphology, **41**(2): 171–181. (in Chinese)

Gu Deyu, Xu Dewei and Chen Haiying. 2003. Progress in remote sensing of red tide and algorithm study [J]. Remote Sensing Technology and Application, **18**(6): 434–440. (in Chinese)

He Jianbang and Jiang Jingtong. 1995. General Review of GIS in China and consideration for its further development [J]. Acta Geographica Sinica, **50** (Supp.): 13–23. (in Chinese)

He Yanbo, Yang Kun and Yang Bailin. 2001. Establishment of spatial database for hydrological model [J]. Guizhou Geology, **67**(2): 84–88. (in Chinese)

Higgitt, D.L. and Lu, X.X. 2001. Sediment delivery to the three gorges [J]. Geomorphology Volume, **41**(2): 143–156.

Hu Yuanan , Cheng Shengtong and Jia Haifeng. 2003. Hydrologic simulation in NPS models: Case of application of SWAT in Luxi watershed [J]. Research of Environmental Sciences, **16**(5): 29–43. (in Chinese)

Huang G.H. and Xia Jun. 2001. Barriers to sustainable water-quality management [J]. Journal of Environmental Management, **61**(1): 1–23.

Jiang Dong, Wang Jianhua, Yang Xiaohuan, *et al.* 2003. Key hydrological parameters retrieved by using remote sensing technique in the Yellow River Basin [J]. Advances in Water Sciences, **14**(6): 736–739. (in Chinese)

Jiang Yi, Li Jianfen and Kang Hui. 2003. A remote sensing analysis of coastline changes along the Bohai Bay muddy coast in the past 130 years [J]. Remote Sensing for Land & Resources, **4**(58): 54–59. (in Chinese)

Koneff, Mark, D. and Andrew, Royle, J. 2004. Modelling wetland change along the United States Atlantic Coast [J]. Ecological Modelling, **177**(1–2): 41–59.

Li Sihai, Wang Hua and Jiang Xingwei. 2003. Application of CBERS-1 CCD in the mangrove remote sensing survey [J]. Marine Science Bulletin, **22**(6): 30–35. (in Chinese)

Li Xiuzhen, Duning Xiao, Rob, H. *et al.* 2003. Spatial modelling on the nutrient retention of an estuary wetland [J]. Ecological Modelling, **167**(1–2): 33–46.

Li Zhongshan, Xu Dezhi, Guo Chuanxin, *et al.* 1999. The Management of east-Liao river valley water environmental information based on GIS [J]. Research of Environmental Sciences, **12**(5): 60–62. (in Chinese)

Ma Tiemin, Shao Lanxia and Cao Yanqiu. 2001. Establishment and application of remote sensing hydrological model in Huifa River basin of Jilin Province [J]. Journal of Northeast Normal University, **33**(4): 93–98. (in Chinese)

NWAP. 2002. China National Wetland Conservation Action Plan. State Forestry Administration, P.R. China. Bejing: China Forestry Publishing House

NWCP. 2002. National Wetlands Conservation Program, 2002–2030. State Forestry Administration, P.R. China. Beijing: China Forestry Publishing House

Pan Zhiqiang, Liu Gaohuan. 2003. Evapotranspiration research of Yellow River Delta using remote sensing method [J]. Geo-information Science, **3**: 91–96. (in Chinese)

Shen Fang and Kuang Dingbo. 2003a. Remote sensing investigation and analysis for water resources utilization and its dynamic change of representing mid-or small lake groups in Taihu drainage area [J]. Journal of Remote Sensing, **7**(3): 221–227. (in Chinese)

Shen Fang and Kuang Dingbo. 2003b. Remote sensing investigation and survey of Qinghai Lake in the past 25 years [J]. Journal of Lake Sciences, **15**(4): 289–296. (in Chinese)

Smith Stephen, M., Dale, E. and Gawlik, Ke. 2003. Assessing drought-related ecological risk in the Florida Everglades [J]. Journal of Environmental Management, **68**(4): 355–366.

Tong Qingxi, Zheng Lanfen, Wang Jinnian, *et al.* 1997. Study on imaging spectrometer remote sensing information for wetland vegetation [J]. Journal of Remote Sensing, **1**(1): 50–60. (in Chinese)

Wan Hongtao, Wan Qing and Zhou Chenghu. 2000. The development of hydrological model [J]. Geo-information Science, **4**: 46–50. (in Chinese)

Wang Aihua, Zhang Shuqing and He Yanfen. 2002. Study on dynamic change of mire in Sanjiang plain based on RS and GIS [J]. Scientia Geographica Sinica, **22**(5): 636–640. (in Chinese)

Wang Jianhua, Jiang Dong, Wang Hao, *et al.* 2003. Retrieval of annual precipitation in the Yellow River by remote sensing [J]. Resources Science, **25**(6): 813–814. (in Chinese)

Wang Ning, Zhu Yanming and Xu Chonggang. 2002. Appling GIS to the quantity study of run off pollutants in watershed [J]. Journal of Northeast Normal University, **34**(2): 92–98. (in Chinese)

Wu Suli, Lou Quansheng, Quan Zhijie, *et al.* 2003. Study of setting up the forest resources management information system based on WebGIS [J]. Chinese Geographical Science, **13**(1): 56–61. (in Chinese)

Xu Xuegong, Lin Huiping and Fu Zaiyi. 2004. Probe into the method of regional ecological risk assessment—a case study of wetland in the Yellow River Delta in China [J]. Journal of Environmental Management, **70**(3): 253–262.

Yang Xiaojun, Michiel, C.J.D, Robert, A., *et al.* 1999. Satellite remote sensing and GIS for the analysis of channel migration changes in the active Yellow River Delta, China [J]. International Journal of Applied Earth Observation and Geoinformation, **1**(4): 146–157.

Yang Zedong, Xu Xiaolei and Gu Feng. 1999. Remote sensing investigations on the lake shore collapsing and silting of Lake Chao [J]. Remote Sensing for Land & Resources, **42**(4): 1–6. (in Chinese)

Yue Tianxiang, Liu Jiyuan, Sven Erik Jørgensen, *et al.* 2003. Landscape change detection of the newly created wetland in Yellow River Delta [J]. Ecological Modelling, **164**(1): 21–31.

Zhang Jiqun, Zhou Chenghu, Xu Kaiqin, *et al.* 2002. Flood disaster monitoring and evaluation in China [J]. Global Environmental Change Part B: Environmental Hazards, **4**(3): 33–43.

Zhang Weidong and Xie Qingsheng. 2002. The exploration of GIS decision making system for water pollution controlling in Chaohu valley [J]. Journal of Anhui Agricultural Sciences, **30**(4): 493–495. (in Chinese)

Zhao Bin, Urs Kreuter, Li Bo, *et al.* 2004. An ecosystem service value assessment of land-use change on Chongming Island, China [J]. Land Use Policy, **21**(1): 139–148.

Zhao Xiaomin and Fu Jianchun. 2003. Study on sandy land investigation by remote sensing and its control in Poyang Lake region [J]. Research of Soil and Water Conservation, **10**(4): 94–96. (in Chinese)

Zhou Huiping, Xu Youpeng and Ge Xiaoping. 2003. Application and analysis of GIS-based on-point source pollution model [J]. Bulletin of Soil and Water Conservation, **23**(3): 60–63. (in Chinese)

Zhu Xueqin, Pan Shibing and Zhang Jianli. 2003. Review of the integration of watershed hydrological model and geographic information system [J]. Geography and Geo-Information Science, **19**(3): 10–13. (in Chinese)

Zhu Zhenhai, Huang Xiaoxia, Li Hongga, *et al.* 2002. Review and prospect of remote sensing in China [J]. Progress in Geophysics, **17**(2): 310–316. (in Chinese)